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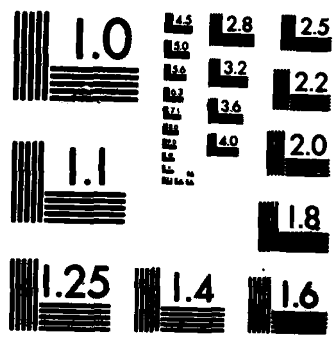
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Aerodynamics Technical Memorandum 359

SOME FACTORS AFFECTING THE SELECTION OF THE TYPE OF NEW TRANSONIC TUNNEL TO BEST MEET AUSTRALIAN NEEDS

by

N. Pollock

Approved for Public Release

DECEMBER 1983

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SUMMARY

A consideration of the new transonic wind tunnel options identified at the Dec. 1982 workshop held at ARL is presented. Factors discussed include, Reynolds number requirements, test section dimensions, operating pressure, individual run duration, total available testing time and operating costs.

It is concluded that, despite the lower test Reynolds number capability, a continuous flow, conventional fan driven tunnel is more suited to Australian requirements than an intermittent blowdown tunnel. If a significant supersonic requirement existed this preference would probably be reversed.

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CONTENTS

1. INTRODUCTION

Following a recommendation from the Australian, Science and Technology Council (ASTEC)[1] an investigation into new aerodynamic test facility requirements for Australia has been carried out at ARL and WSRL. A survey of the needs for such new facilities and ways in which the identified needs could be met are presented in References 2 and 3. As part of this investigation two prominent international wind tunnel design consultants, DSMA International Inc. of Toronto, Canada and Sverdrup Technology Inc. of Tullahoma, USA, were engaged to undertake conceptual design studies of new wind tunnels to meet Australian needs. On the 9th and 10th of December 1982 a workshop[4] on the topic "Needs For More Capable Wind Tunnels in Defence Support Laboratories" was conducted at ARL. This workshop was attended by representatives from the Defence Forces, Industry, Research Organizations and Academic Institutions.

From the investigations conducted at ARL and WSRL, the recommendations of the two consultants and the conclusions reached at the workshop there is overwhelming agreement that a new transonic wind tunnel for Australia is urgently required. It is also clear from the work carried out up to now that the only practical facility types to meet local needs are a continuous flow closed circuit, compressor driven tunnel or an intermittent blowdown tunnel.

Neither of these tunnels meets all of our requirements and an assessment of the advantages and disadvantages of the two types is required. It is the aim of this paper to contribute to this assessment.

2. FACTORS AFFECTING TUNNEL SELECTION

2.1 Reynolds Number Requirements

One of the important areas in which the capabilities of the two contending tunnel types differs is that of available test Reynolds number. Based on the costing information provided by the consultants it appears that for a blowdown tunnel costing about $25M (1981 Australian Dollars) a maximum Reynolds number (Re) of 10×10^6 to 13×10^6 (based on $0.1 \times \sqrt{\text{Test section area}}$) is available in the transonic speed range. This Re meets the requirement suggested in Reference 3 which was formulated on the basis of arguments presented in Reference 5. For a continuous tunnel of the same cost a maximum test Re about half that of a blowdown tunnel would be available. Since this Re difference is such a fundamental factor it was considered worthwhile to reassess its importance.

During the past decade there have been a number [5-9] of investigations into what test Re is required to achieve an acceptable representation of the full scale flow. Viewed critically, there is some evidence to suggest that the conclusion as to the minimum acceptable test Re reached in these investigations was influenced by the capabilities of the facility which was planned at the time. There also appears to be a trend for more recent investigations to recommend a higher Re. The situation now appears to have been reached in the USA and Europe where the consensus of opinion is that nothing short of full scale Re's are required. The

conviction with which this view is held is evidenced by the construction of the NTF in the USA and the advanced planning of the ETW in Europe. It has been argued that these extreme test Re requirements are only relevant to high aspect ratio transport configurations and not to combat aircraft. In an attempt to test this assertion a survey of published test results on various configurations was undertaken.

Over the years there have been an enormous number of tests on aircraft configurations many of which contain information of the effect of Re. Unfortunately they also contain information on tunnel flow quality, wall interference, model fidelity, model aeroelastic behavious and support interference. In virtually all cases it is difficult, if not impossible, to positively identify the contribution of the various factors mentioned above. This is graphically demonstrated by the NACA 0012 lift curve slope data (Fig 1) presented by McCroskey during the discussion at the May 1982 AGARD conference on Wall Interference in Wind Tunnels[20]. However in the Author's view the following conclusions regarding Re can be drawn.

a. Different aircraft configurations vary widely in their Re sensitivity. This sensitivity is also highly dependent on the part of the operational envelope under consideration. Generalizations on Re sensitivity are difficult. Significant effects have been noted at Mach numbers from 0.16 to 1.0, for high and low lift conditions and for both high and low aspect ratio configurations.

b. There is general agreement that a chord Re of 1×10^6 is the absolute minimum for any worthwhile testing regardless of configuration. The evidence suggests that this should be viewed as a minimum tip chord Re rather than simply a mean chord Re.

c. There is no convincing evidence that there is any generally applicable sub full scale Re above which Re effects can be neglected. The best controlled experiments (see for example Reference 10), which unfortunately only extend to a chord Re of 5×10^6, show a steady monotonic change of a Re sensitive parameters throughout the test range.

d. For particular configurations at particular test conditions there is the possibility of a minimum acceptable Re below which the test flow pattern is completely different from the full scale one. This occurs most commonly when the nature of the stall changes[11], say from the thin aerofoil type to the leading edge type.

There is no generally applicable Re for these discontinuous flow changes and the only defence against them is an awareness on the part of the test engineer of the fundamental flow conditions on the model he is testing.

e. For many, but not all, configurations there is a chord Re in the range 2.5×10^6 to 4×10^6 where higher Re conditions can be simulated using the trick of aft transition fixing [12]. It would be clearly advantageous for a wind tunnel to have access to the Re range.

f. To facilitate the extrapolation of test results to full scale it is helpful if the test Re can be varied over a range of at least 2 to 1.

The best controlled investigations into the effect of test Re have been carried out on two dimensional aerofoils. Despite the fact that these tests are highly idealized they can give considerable insight into the behaviour of full aircraft configurations. These tests[13-15] show that the characteristics of most aerofoil sections are still changing significantly at Re values of 30 X 10^6 to 40 X 10^6. These Re's are well into the full scale flight range. For some modern supercritical sections this Re effect is quite large as shown in Figure 2 which is redrawn from Reference 15.

On the basis of the factors discussed in this section the following observations on the Re requirements of new tunnels can be made:

a. The highest possible test Re consistent with tunnel cost and the appearance of other adverse tunnel operating characteristics is required. However there is no Re value above 1 X 10^6 (based on chord) which separates acceptable from fundamentally unacceptable testing capability.

b. The tunnel should be capable of testing over a Re range of at least 2 to 1 in the Mach number range 0.5 to 1.4 without dropping below the minimum value of 1 X 10^6.

c. It would be highly advantageous for the tunnel to be capable of operating at chord Re values of 2.5 X 10^6 to 4 X 10^6 in the high subsonic speed range.

These requirements do not preclude either of the proposed tunnel types but favour the higher Re capability of the blowdown tunnel.

2.2 Test Section Dimensions

The test section dimensions are a fundamental parameter which must be established early in a tunnel design program. These dimensions are particularly critical because the tunnel cost, irrespective of type, vary with the linear dimensions raised to a power between 2 and 3. Considering first the test section shape; there is a high level of agreement that a square shape is the best compromise for general aircraft testing. Turning to size; the most important impact of test section dimensions, apart from the obvious effect on Re, is on the design and manufacture of test models. There is general agreement that aircraft models with extensive pressure tappings or with remotely set control actuators cannot be economically manufactured with a span less than 0.6m to 0.8m. Based on this fact and the current state of knowledge on wall interference, both consultants agreed that the minimum practical test section size is 1.5m X 1.5m.

The author considers that there is evidence that a larger test section size would be needed for very complex models involving many adjustable control surfaces and/or representative elastic structures, like for example the FA-18. There is strong evidence that the cost of a tunnel with a test section 2m square or larger would be prohibitive. The possible range of test section dimensions is therefore in the range 1.5m to 2m. The advantages acruing from small increases in the test section size should not be underestimated. Although the Re gain is negligable the greater freedom in model design may make very large differences to test accuracy and productivity.

2.3 Operating Pressure

There is general agreement that any tunnel suitable for Australia would use ambient temperature air as a test gas and as pointed out in the previous section, the practical range of test section sizes is very limited. These two facts combine to leave the use of high stagnation pressure as the only path to increased test Re. The Re difference between the continuous flow and blowdown options reflects their different operating pressures. For a practical blowdown tunnel the maximum stagnation pressure in the transonic speed range, set by minimum run time considerations, is about 700 kPa and the minimum pressure, set by the atmospheric exhaust starting limit, is about 150 kPa. For a practical continuous flow tunnel of similar cost to a blowdown tunnel the maximum stagnation pressure, set by cost and peak power considerations is about 300 kPa and the only minimum pressure limit is set by the capacity of the tunnel pressurisation plant.

As higher tunnel pressures are utilised increasing problems with model strength, support strength and non representative aeroelastic distortions would be experienced. An investigation[5] into these problems concluded that for the high strength steels currently used for wind tunnel models (ultimate tensile strength 1.0 GNm^{-2}) the static pressure for high lift testing should be limited to 280 kPa at transonic speeds. This is equivalent to a stagnation pressure of about 450 kPa. If maraging steels with an ultimate strength of around 2.0 GNm^{-2} were used this stagnation pressure limit would be around 900 kPa. Unfortunately these steels are difficult to fabricate and have rather poor fatigue properties. For these limiting stagnation pressures the supporting sting required for the model would contribute significant interference and in most cases involve quite considerable modifications to the geometry of the rear of the model. It would also preclude any intake flow modelling. The situation regarding aeroelastic distortion at these high pressures is described very well in Reference 5 and conclusion from the appropriate section of that Reference is reproduced below:

"The main conclusion to draw from this section is that even over the restricted range of flight conditions for which model tests at high Reynolds number might be thought necessary in order to simulate full-scale flows on current aircraft, the model wing may differ from the aircraft shape by up to 0.4° of twist. From the results of development tests of transport aircraft and of combat aircraft with simulated manoeuvre distortions, it appears that changes in wing twist of this magnitude can have significant effects on stability and buffet margins. Greater errors would be present for future aircraft if it turns out that the range of tests on one model has to be extended to cover flight conditions down to 1g and more than one model might be needed to provide an alternative datum. For the more highly - tapered and more highly - swept wings of some possible transport aircraft and, again for most combat aircraft, the rate of change of model wing distortion with lift coefficient, for a model with solid wings, may exceed that for the aircraft at high cruising altitude and hence there is no scope for improved aeroelastic modelling other than by reducing tunnel pressure. The model scale must be such that the Reynolds number does not fall too far in consequence of this need to work at lower pressures."

It must be remembered that the above conclusion was written in 1971 well before very elastic aircraft like the F/A-18 entered service. The situation today is therefore considerable more difficult than the above words imply.

On the basis of the material presented in this section the Author considers that it is doubtful whether testing at above about 400 kPa stagnation pressure yields any significant increase in data accuracy. The gains from better Re scaling are likely to be largely offset by errors introduced by support interference and non-representative aeroelastic deflections.

It should be noted that all the above conclusions are based on the use of solid steel models. If more complex models incorporating pressure tappings, mechanically actuated control surfaces or elastically scaled structures were used, the tunnel operating pressure would have to be further restricted. One class of complex test which is of particular importance to Australia is that of captive trajectory store release. It is understood that in the AEDC 4T tunnel where much of the USA's store release work is carried out, it is normal practice to use stagnation pressure equal to or below atmospheric. The reductions in model and supporting rig deflections are judged to be of greater importance than the loss in Re.

Current forecasts of materials developments over the next 30 years suggest that, for practical engineering materials suitable for model manufacture, gains in stiffness and strength of only about 50% over current maraging steels are possible. During a recent overseas trip by the Author there was a consensus of opinion among major tunnel operators that advanced materials would not lead to significantly stronger or stiffer models in the foreseeable future.

The implication of the above considerations is that much of the Re advantage of the blowdown over the continuous flow tunnel cannot be used effectively for many tests. This clearly reduces the real importance of the Re difference between the two facility types.

2.4 Individual Run Duration

Blowdown tunnels of the type under consideration have a maximum run duration which varies from about 10 sec at the maximum Re to about 60 sec at the minimum operating Re. Continuous compressor drive tunnels with adequate installed cooling capacity have no inherent run duration limit. It is generally agreed that all normal static and dynamic[16] transonic tests can be carried out in less than 10 sec. It is known that at least one blowdown tunnel in the world has the capability to carry out captive trajectory store release tests, presumably only near its lowest Re. However there is no doubt that store release tests would be easier if they were not carried out under a strict time limit.

The short run duration of the blowdown tunnel coupled with the fact that the test section is at atmospheric pressure between runs has the advantage that regular and rapid model access is available. On balance it is considered that the different run durations do not lead to a clear preference for either facility type.

2.5 Total Available Testing Time

Allowing for tunnel pressurisation, depressurisation, run up, run down and model changing time it is not unreasonable to assume a total single shift wind-on test time availability of about 4 hour/day for a

continuous tunnel. A blowdown tunnel with a typical compressor plant would be capable of providing about 5 min/day of wind-on test time at the same Re as the continuous flow tunnel. These figures obviously raise questions regarding the relative productivity of the two facilities. It has been argued that using modern instrumentation and continuous sweep model attitude changing[17] very high data rates can be obtained from a blowdown tunnel. While this is true it must be remembered that high data rates are only obtained at the expense of data precision. As pointed out in References 18 and 19 data accuracy is a function of the RMS noise level of the data, the frequency spectrum of the noise and the averaging time used. For wind tunnel data the noise sources are tunnel flow unsteadiness, test section noise and model-balance vibrations. To give some idea of the averaging times required it has been estimated[18] that for a reasonably typical set of test conditions a time of 0.4 sec is needed to obtain 0.1% accuracy.

Rapid incidence sweeps have an additional disadvantage in that no existing wind tunnel control system can maintain the flow Mach number at a constant value during a rapid change in model drag. Therefore to obtain data at a particular Mach number it would be necessary to take additional test points and interpolate. The importance of this problem depends on the Mach number sensitivity of the tests being conducted. However for much of the transonic speed range, Mach number changes approaching to static accuracy of the tunnel speed measuring system have a measurable effect on the data. It is therefore considered that even small changes in tunnel speed during an incidence sweep would involve a significant increase in the number of data points required.

The Author considers that there is no fundamental difference between the wind-on data productivity of blowdown and continuous tunnels and the potential productivity of the two tunnel types is therefore in the ratio 4 hours/day to 5 min/day ie. ≅ 50:1. It is accepted that current blowdown tunnels tend to gather data more rapidly than continuous flow tunnels and this is taken as evidence that there is real productivity pressure in blowdown facilities due to their low available testing time. The importance of store release testing in the identified Australian needs produces considerable pressure on tunnel productivity. When a number of different store types can be released from a number of different carriage positions on the aircraft it is easy to produce a large number of combinations which must be checked. When variations to release Mach number and aircraft attitude are also considered it is relative by easy to envisage a test program which would very heavily load a blowdown tunnel.

2.6 Operating Costs

A blowdown tunnel is considerably less energy efficient than a continuous flow tunnel. Based on data provided by the two consultants it appears that the energy consumption ratio for a given Re and test time is about 30:1. To indicate the significance of this ratio on operating cost; the electric power charge to operate a blowdown tunnel of the size proposed for a single shift would be about $1M per year based on Nov. 1983 State Electricity Commission of Victoria rates. The energy consumption ratio between the two tunnel types would only be directly reflected in the operating costs if the higher peak power demand of the continuous flow tunnel can be supplied on the same tariff basis as the lower peak demand of the blowdown tunnel. Current indications are that for the tunnel sizes under consideration the power would be supplied on the

same tariff for both tunnels. For a continuous tunnel with a Re capability equal to the blowdown tunnel these are strong indications that some penalty tariff and/or operating limitations would be applied.

Over the projected life of the tunnel the difference in energy consumption has the potential to make a significant difference to the total life cycle cost. The maintenance costs for the two facility types and the staff levels required to operate them are believed to be similar.

3. COMPARISON BETWEEN BLWODOWN AND CONTINUOUS FLOW TUNNELS

The advantages and disadvantages of the two tunnel types are listed below. This comparison is made on the basis of facilities of similar capital cost.

a. Blowdown

Advantages:

i. Full test Reynolds number identified as necessary in Reference 5.

ii. Supersonic test capability to Mach 4 can be provided for little extra cost.

iii. Model failure unlikely to damage tunnel.

iv. Regular access to model available after each run.

v. Large high pressure air storage available to operate other facilities.

Disadvantages:

i. High minimum stagnation pressure set by atmospheric exhaust operation would limit use of fragile models.

ii. Low total run time in transonic speed range.

iii. Short individual run duration for high Reynolds number operation.

iv. Poor energy efficiency.

v. Flow quality possibly inferior to continuous tunnel.

b. Continuous flow

Advantages:

i. No fundamental lower limit to operating pressure - very fragile models could be tested.

ii. Virtually unlimited individual run duration.

iii. Large total run time available.

iv. Proven capability to provide high quality flow.

v. High energy efficiency.

vi. Large electric motor and precision speed controller available to drive other facilities.

Disadvantages:

i. Only about half the desired test Reynolds number identified in Reference 5.

ii. Cannot easily be extended to provide a test capability outside the Mach number 0.3 to 1.4 range.

iii. Model failure could cause extensive damage to tunnel.

iv. For operation other than at atmospheric pressure tunnel must be depressurised for model access.

Efforts have been made to quantify the above advantages and disadvantages so as to give a quantitative preference for one type over the other. A number of people involved in transonic wind tunnel testing at ARL have independently given a numerical score to each of the above points and, although the individual scoring varies, a distinct preference for a continuous tunnel emerges. It must be emphasised that this preference is the consequence of Australia's particular projected needs over the next 20 years and may not be the same as the preference arrived by others with different requirements.

The critically factors in favour of each facility are the Re capability and supersonic test capability for the blowdown tunnel and the lower minimum pressure limit and longer available testing time for the continuous flow tunnel. The supersonic capability of the blowdown tunnel could not be given a great amount of weight since the workshop concluded that this speed regime was of low priority. The apparently major importance of the higher Re capability of the blowdown tunnel has in the light of some reassessment been downgraded. The major reasons for this are:

a. For captive trajectory store release tests and static and dynamic aeroelastic investigations it is highly unlikely that the tunnel Re capability could be utilised due to model load problems. Indeed it is doubtful whether some of these tests could be conducted at all, even at the lowest available stagnation pressure. Since these classes of test are of major importance to the RAAF this limitation considerably reduces the value of the high Re capability. It seems likely that even conventional tests at high incidence near the buffet boundary would not be able to use the full Re capability due to model strength limitations.

b. Even where a model of adequate strength could be provided it appears that increasing support interference and non-representative aeroelastic distortions would reduce the gains in test accuracy resulting from the higher Re.

The fact that any new transonic tunnel would be the only significant facility of its type in Australia for at least 20 years leads to a preference for a versatile tunnel which would carry out the major part of the identified potential workload. It is considered that, due to its

large available testing time and its wide operating pressure range, the continuous flow tunnel is the more versatile of the two. It is suggested that the high Re check tests that would be required from time to time should be contracted to overseas facilities.

4. CONCLUSION

Following the workshop on new wind tunnels held at ARL on 9th and 10th December 1982 there was general agreement that the provision of a new transonic wind tunnel was very important. It was further agreed that a new tunnel would be either a conventional continuous flow compressor driven facility or an intermittent blowdown type. The investigation reported here aimed at providing some of the information required for an informed decision to be made on the best type of tunnel for Australian needs.

It is concluded that neither tunnel type, built within a reasonable capital cost, could meet all the performance requirements identified in preliminary studies. It is therefore thought reasonable to identify the facility which could carry out the majority of the projected testing leaving a minority to be contracted to overseas facilities. The wide variety of testing identified and the significant workload in the areas of captive trajectory store release testing and aeroelastic investigations lead to a clear preference for a continuous flow tunnel. The critical factor in this choice is the judgement that the wide operating pressure range and high productivity of the continuous flow tunnel more than outweighes the higher maximum Re capability of the blowdown tunnel.

Any new tunnel would operate for at least 20 years and possibly up to 50 years so care should be taken in the design not to preclude future development of the facility or to incorporate features which would limit its future test capabilities. When a continuous tunnel is designed two features which can never be easily changed are the test section dimensions and the shell pressure limit. It is therefore strongly suggested that, if economically possible, the shell should be designed for at least 400 kPa and the test section dimensions should exceed the minimum values of 1.5m X 1.5m.

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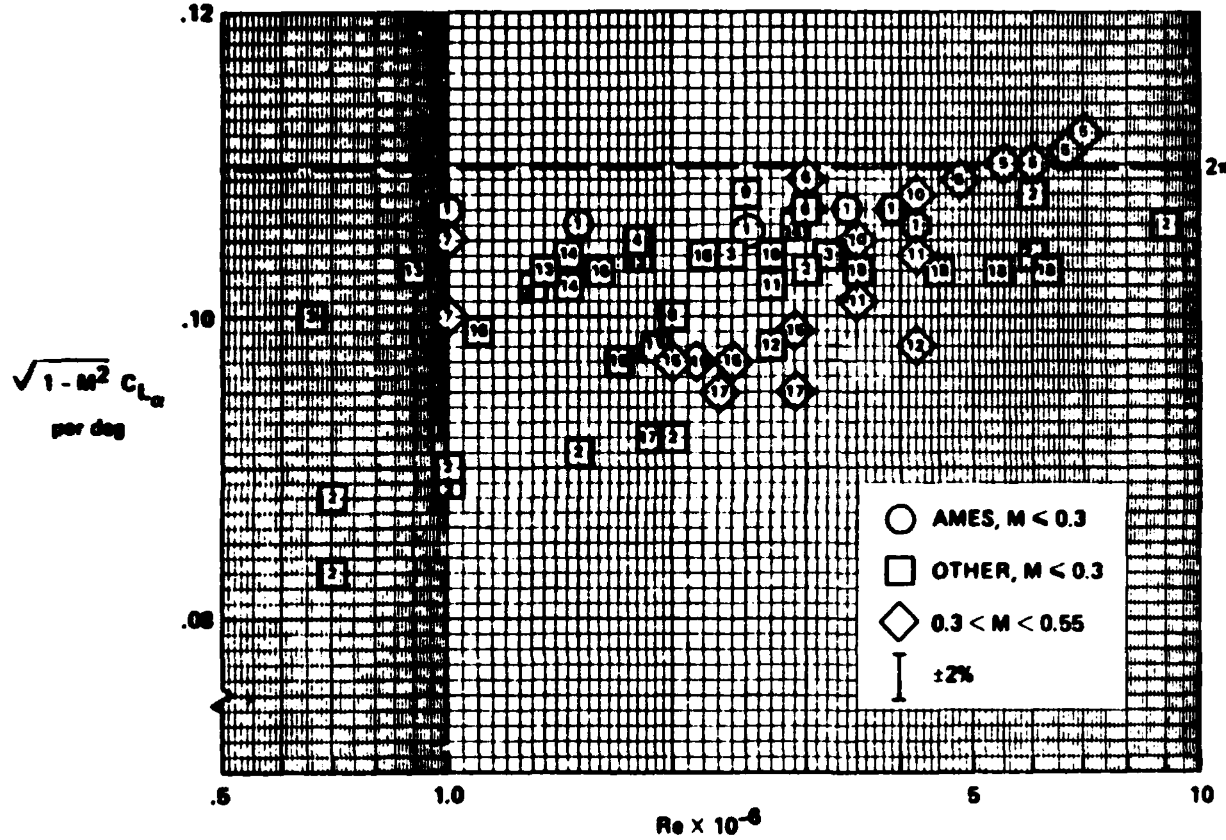

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2	NACA TN 1945
3	NACA Report 586
4	NACA TN 3361
5	NASA TMX 73990
6	NASA TM 81927
7	CALSPAN RK-5070-A-3
8	AIAA J. Dec 1974 p 1771
9	NASA TP 1100
10-12	UTRC 8-ft; var. sources
13	RAE TR 68303
14	NPL Aero Rep. 1308
15	ARC CP-1261
16	ONERA Doc. 76 /1157.AN
17	AGARD AR-138
18	NACA TM 1240

FIG. 1 NACA 0012 LIFT CURVE SLOPE DATA FROM VARIOUS SOURCES.

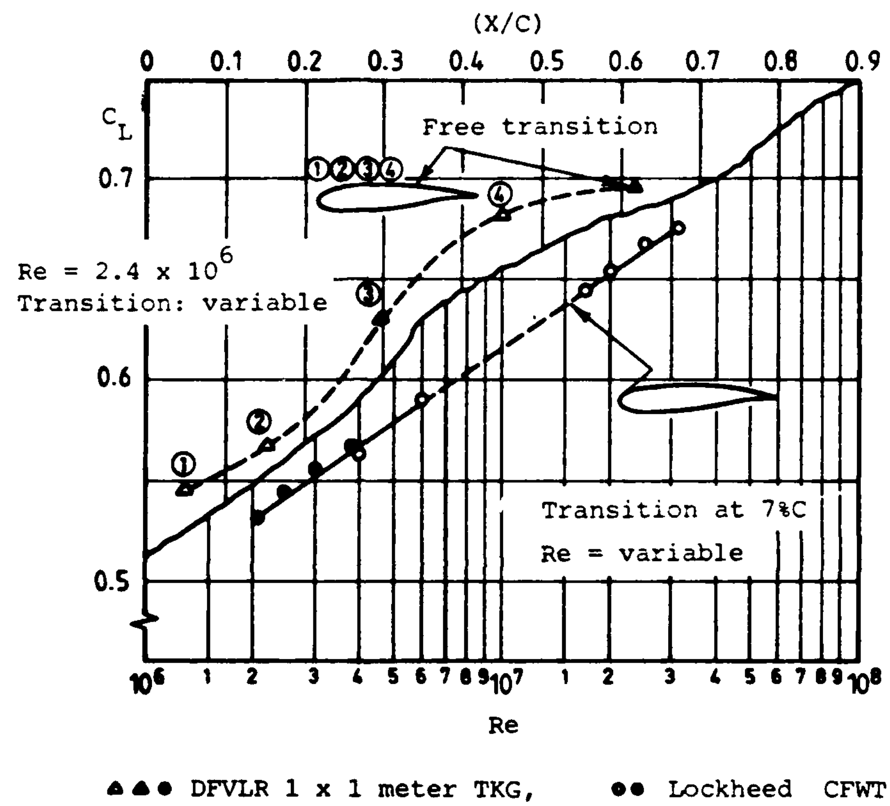

FIG. 2 EFFECT OF REYNOLDS NUMBER AND TRANSITION STRIP LOCATION, AIRFOIL CAST 10-2/DOA2, $M_\infty = 0.765$, $\alpha = 2°$.

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AR-002-995	ARL-AERO-TECH-MEMO-359	DECEMBER 1983	DST 83/018

4. Title	5 Security a document:	6. No Pages
SOME FACTORS AFFECTING THE SELECTION OF THE TYPE OF NEW TRANSONIC TUNNEL TO BEST MEET AUSTRALIAN NEEDS.	UNCLASSIFIED	11
	b title: U c abstract: U	7. No Refs: 20

8. Author(s)	9. Downgrading Instructions
N. POLLOCK	

10. Corporate Author and Address	11 Authority (as appropriate)
AERONAUTICAL RESEARCH LABORATORIES P.O. BOX 4331, MELBOURNE VIC 3001	a.Sponsor b.Security c.Downgrading d.Approval

12. Secondary Distribution (of this document)

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14. Descriptors	15. COSATI Group
TEST FACILITIES TRANSONIC WIND TUNNELS DEFENSE PLANNING	0101 1402

16. Abstract

A consideration of the new Transonic Wind Tunnel options identified at the Dec. 1982 workshop held at ARL is presented. Factors discussed include, Reynolds number requirements, test section dimensions, operating pressure, individual run duration, total available testing time and operating costs.

It is concluded that, despite the lower test Reynolds number capability, a continuous flow, conventional fan driven tunnel is more suited to Australian requirements than an intermittent blowdown tunnel. If a significant supersonic requirement existed this preference would probably be reversed.

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16. Abstract (Contd)

17. Imprint

AERONAUTICAL RESEARCH LABORATORIES, MELBOURNE.

18. Document Series and Number	19. Cost Code	20. Type of Report and Period Covered
AERODYNAMICS TECHNICAL MEMORANDUM 359	516110	

21. Computer Programs Used

22. Establishment File Ref(s)

A2/38